AEROMAGNETIC INVESTIGATIONS ON THE CONTINENTAL SHELF OF NORWAY, STAD-LOFOTEN (62—69°N) [1]

By

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Abstract.

An aeromagnetic isogam map based on measurements by Norges geologiske undersøkelse 1965—67 is presented and interpreted.

The map reveals several interesting geological features, the most important of which is the existence of a large sedimentary basin situated parallel to the coast with its axis 120—150 km from the coastline, having widths above 200 km and maximum depths to magnetic basement exceeding 10 km.

Introduction.

After having gained a considerable amount of experience during years of aeromagnetic surveying in Norway, Norges geologiske undersøkelse, Geofysisk avdeling started to look seawards in 1962. Having successfully done some offshore mapping in Skagerak 1962—63 on behalf of Universitetet i Bergen (Aalstad and Sellevoll, in preparation), the Institution felt prepared to face the problems of the vast and practically unexplored Norwegian shelf areas. The geological knowledge concerning this part of Norway was rather sparse at that time, amounting to a few erratic boulders and a small downfaulted area of Mesozoic age (Ørvig, 1960). This indicated the possibility of younger sediments existing in the continental shelf outside the marginal chan-

1) Publication No. 1 in NTNF's continental shelf project.
Publication No. 16 in the Norwegian geotraverse project.

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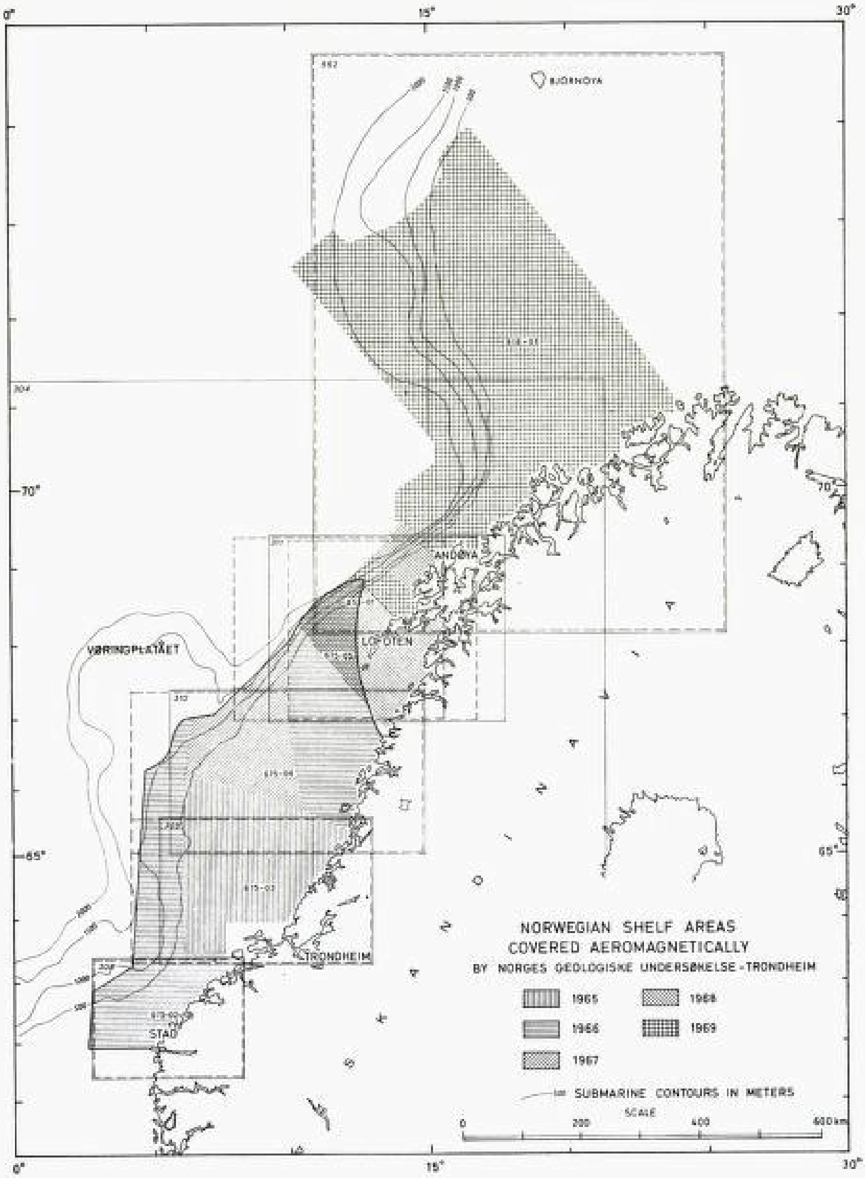

Fig. 1. Location map.

nels along which the Scandinavian landmass was supposed to have been uplifted during Tertiary times (Holtedahl, 1960b). The results of a seismic refraction profile (Ewing and Ewing, 1959, Profile F-8) definitely settled the speculations by showing a sedimentary sequence of at least 4.5 km overlying a doubtful basement. Later (Manum, 1966), Upper Cretaceous sediments were dredged from the continental rise west of Andøya (69° 30′N, 15° 40′E).

In 1963 10 profiles were flown normal to the coast between Stad and Lofoten (62—68°N). The profiles showed a definite change in magnetic pattern when passing from land to sea, and a rough interpretation in terms of depth to magnetic basement gave an elongated basin lying parallel to the coast and with maximum depths exceeding 7 km. With these encouraging results the survey was extended further to the north to include 20 profiles between Lofoten and Senja (68—69°30′N) in 1964.

After these reconnaissance flights, detailed surveying was started in 1965 and is still going on in 1970. The measurements have been conducted by the Institutions section for airborne measurements headed by Henrik Håbrekke. In 1965—66 the measurements were supported financially by NAVF (The Norwegian Research Council for Science and the Humanities). From 1967 surveying has been financed by NTNF (The Royal Norwegian Council for Scientific and Industrial Research). The areas flown until now, covered by approximately 85 000 line kilometers, are shown in Fig. 1. The area with which we shall be dealing in this paper is situated between Stad and Lofoten and is indicated by solid outline .

Acquisition and presentation of data.

The intensity in magnetic total field was measured with an Elsec 592 proton magnetometer with potentiometric recorder installed in an aeroplane. The Elsec proton magnetometer reads the total magnetic field, recycling every 1.7 sec, with an accuracy of ±1 gamma.

For navigation purposes two Loran A receivers (Japanese LR 700) were installed in the aircraft and tuned to two different Loran A transmitter combinations on the Norwegian coast and at Jan Mayen. A fiducial marker on the potentiometric recorder was actuated every time a perpendicular Loran A-lane was crossed. Crosspoints were obtained from the second Loran A receiver tuned to the Loran A transmitter combination producing the perpendicular lanes. The accuracy of navigation is set to «better that 500 meters». By correlating Loran A navigation with drafts in the coastal areas, discrepancies were found to be less that 200 meters.

The profiles measured are identical to Loran A-lanes running approximately north-south in the actual area. The distance between profiles was chosen equal to the distance between lanes displaced by 20 microsec, i.e. 4—5 km. Tie-lines, with an average spacing of approx. 50 km, were flown perpendicular to the ordinary lines in order to compensate for diurnal variations. In addition the total field was registered continuously throughout the survey period by means of a stationary magnetometer in Trondheim. The corrected field values are estimated to be accurate within limits ± 5 gammas.

The corrected field values were reduced to 1965-values and four isogam maps on scale 1 : 350 000 with contour interval 20 gammas were constructed. In order to remove a normal and present the anomalous field the International Geomagnetic Reference Field (Fabiano and Peddie, 1969) was subtracted. The residual magnetic field was contoured and redrawn on a 1 : 1 500 000 scale, the result of which is presented here.

Interpretation.

A magnetic isogam map mainly reflects the distribution of magnetite in the ground. As this distribution is principally governed by igneous and metamorphic processes, the magnetic map reveals gross geological features. For instance, magnetic trends and displacement of anomaly axes may reflect tectonic lines and directions.

As only shelf areas are covered by this survey, a regional picture (U.S. Naval Oceanographic Office, 1967) is presented in Fig. 2. From this map it is possible to distinguish between five magnetically different regions.

1. Strong and linear oceanic anomalies.
2. Strong, irregular, and narrow anomalies over Shetland (61°N, 1°W) and to some extent Vøringplatået (67—68°N).
3. Strong, irregular, and broad anomalies along the coast south of Trondheim.

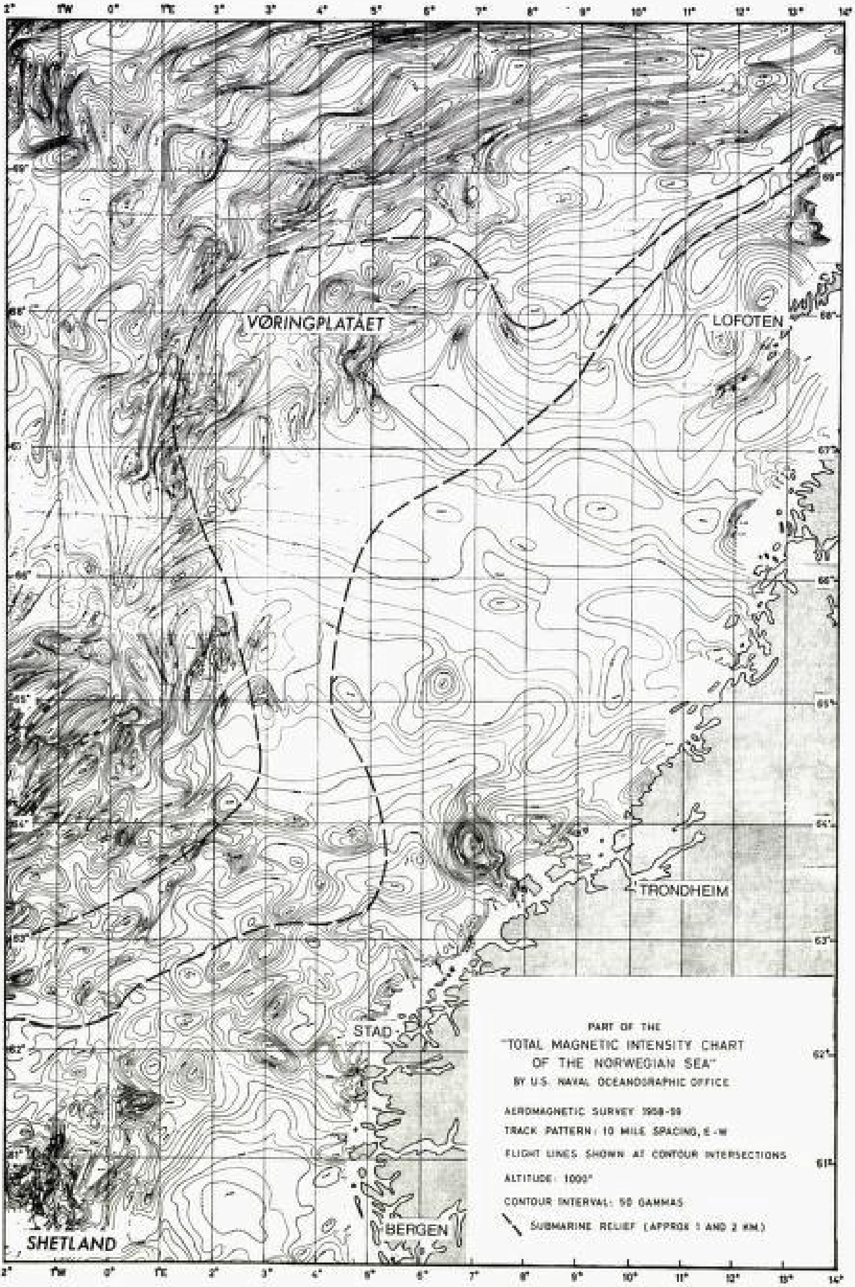

Fig. 2. Aeromagnetic map showing regional features. Reproduction permitted by the U.S. Naval Oceanographic Office.

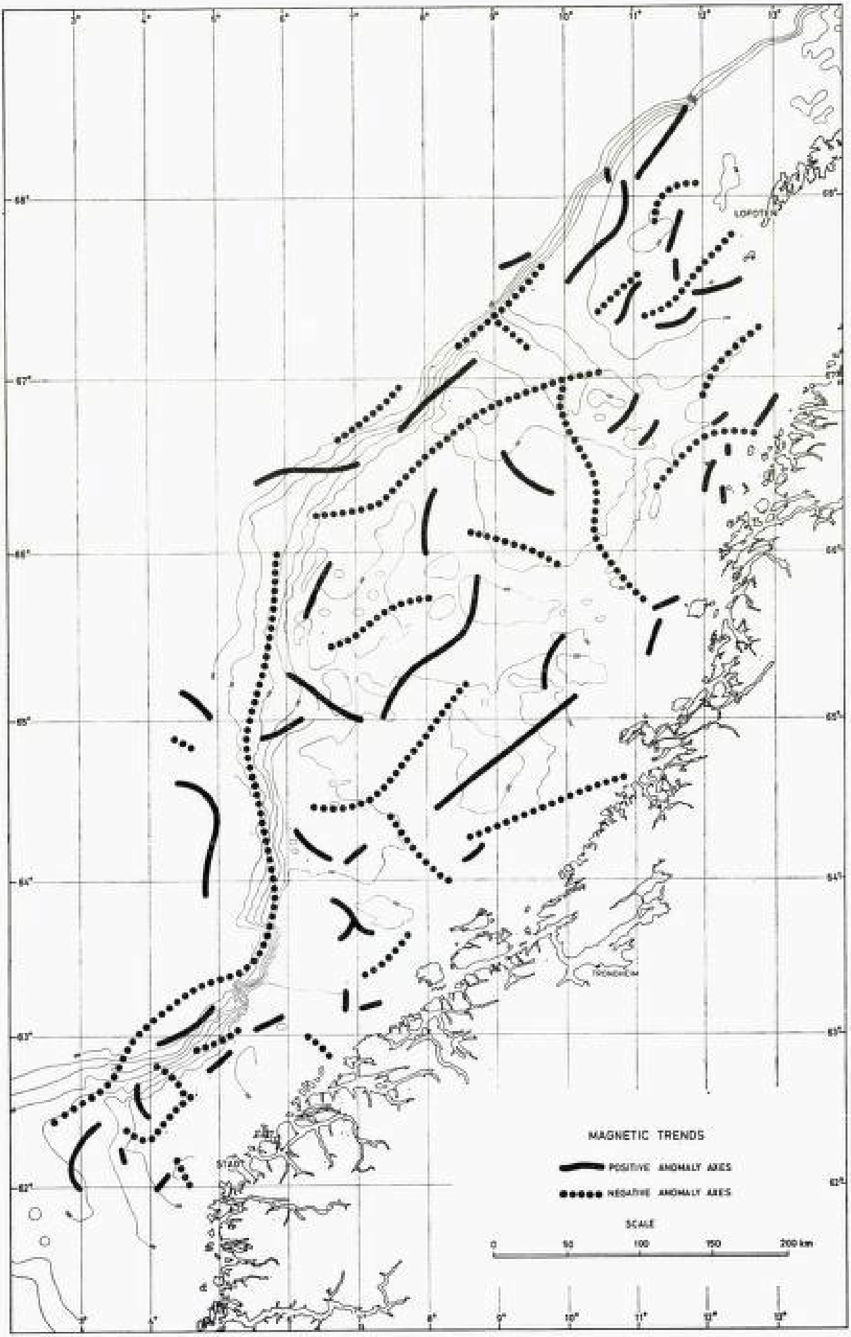

Fig. 3. Map showing magnetic trends.

4. A weak and featureless picture covering the shelf between Trondheim and Lofoten.
5. Very large anomalies in the Lofoten area.

The detailed magnetic isogam map (under separate cover at the end of this book) shows several interesting features.

Magnetics trends.

A close inspection of the map reveals several magnetic directions. For those not familiar with aeromagnetic maps a separate figure containing all the visible directions has been drawn (Fig. 3). The negative axis along the continental edge is peculiar and may lead to comparison with similar anomalies at or near continental slopes in other parts of the world (Taylor et. al., 1968). A direct comparison is, however, not valid as the anomaly in our case is negative, weak, and irregular as opposed to a regular, positive anomaly of several hundred gammas along the eastern continental margin of the United States.

Lofoten.

The Lofoten island group consists of granulite facies charnockitic rocks (Strand, 1960, p. 261). A gravimetric Bouger anomaly of 130 mgals is associated with this province (Norges Geografiske Oppmåling, 1963), and from the isogam map it can be seen that a large aeromagnetic anomaly also occurs over the Lofoten massif. This anomaly clearly shows that the Lofoten granulites continue towards southwest. The similar magnetic anomaly to the west indicates another mass of charnockitic rocks lying parallel to Lofoten and having approximately the same size. A major NW-trending break is indicated in both topography and magnetometry along Trændjupet (67°N, 10°), cutting the Lofoten anomalies to the south. The westernmost mass seems however, to continue on the southern side of the break. A gravimetric Bouger anomaly of 115 mgals (Raw data from Service Central Hydrographique, 1968) associated with the magnetic anomaly strongly supports this interpretation.

Marginal channels.

Another feature is the change in magnetic pattern from narrow to broader anomalies at or near the marginal channels parallelling the coastline. Olaf Holtedahl has drawn attention to this feature and its possible significance in a number of publications, a summary of which will be found in Holtedahl (1960b). Igneous activity is indicated by the small, but distinct, magnetic anomalies along these channels, especially north of 64°N. The aeromagnetic profiles have been thoroughly searched for signs of eventual displacements, but no conclusive evidence has been found. More detailed work is required to prove or disprove the existence of faulting along these depressions. In fact, a limited area has already been measured in detail and is now being interpreted.

Frøyabanken.

The very strong and large anomaly at Frøyabanken (63°50′N, 7°E) deserves some discussion. A study of the analog records shows that it is built up by the growing together of several narrow anomalies having irregular orientations. Also associated with the anomly is a gravity high of more than 60 mgals (Ole Bedsted Andersen, personal communication, 1968).

The most likely explanation for this large magnetic anomaly is that it is due to a magnetic equivalent to the Seiland gabbroic province (Strand, 1960, p. 275) situated at 4—6 km depth. Over the Seiland province there are strong and irregular magnetic anomalies mainly due to ultrabasic layers and lenses in the gabbro, which is itself practically nonmagnetic (Norges geologiske undersøkelse, 1966).

A detailed aeromagnetic survey of the anomaly at Frøyabanken has been conducted and a thorough interpretation is now being done.

Magnetic basement.

The most important result of aeromagnetic surveys over sedimentary basins is the determination of depth to magnetic basement. Significant magnetic anomalies are almost exclusively due to magnetization contrasts in the basement, and less frequently to igneous rocks within the sedimentary column. The form of these anomalies is related to the depth to the top of the magnetic masses. Hence, by studying the form of the anomalies it is possible to determine depths to the magnetic basement which is the same as the thickness of the sedimentary cover. The results are critically examined before doing a generalized contouring of the basement surface, giving less weight to uncertain determinations and values differing to much from the others.

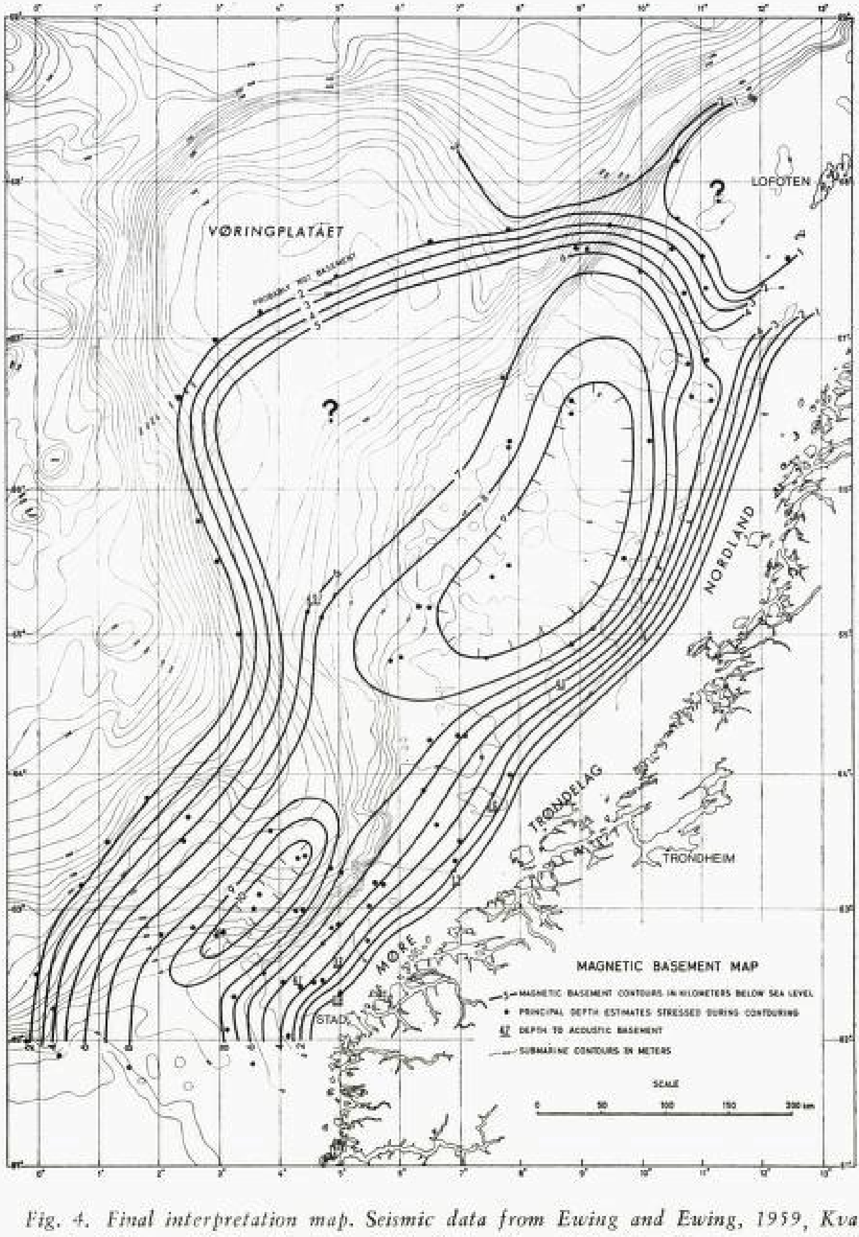

Fig. 4. Final interpretation map. Seismic data from Ewing and Ewing, 1959, Kvale et. al., 1966, and Sellevoll et. al., 1967. Submarine relief after Eggvin et. al., 1963.

In the present case the interpretation has been done directly on the analog records by graphical methods which are to be published in near future (Åm, in preparation). Of already published methods the one of Bean (1966) approaches most closely to those used here.

To get a complete picture of the basin the «Total Magnetic Intensity Chart of the Norwegian Sea» (Fig. 2) and the accompanying microfilm records have been interpreted in the areas not covered by the present survey (An interpretation of this map has already been published (Avery et. al., 1968), but that publication is not concerned with the shelf areas or with any kind of depth determinations). The final interpretation is given in Fig. 4, where the numerous depth determinations inside the 1 km contour have not been plotted.

This interpretation shows the existence of a large sedimentary basin situated parallel to the coast with its axis 120—150 km from the coastline. Along Nordland (65—67°N) the axis is situated not far from the center of the shelf with maximum depths exceeding 9 km. A culmination (7—8 km depths) is indicated outside Trøndelag (64°N). Outside Møre (63°N) the basin deepens again reaching depths of more than 10 km with the axis on the continental rise about 60 km off the shelf.

The central part of Vøringplatået (67—68°N, 4—7°E) is characterized by narrow negative anomalies assumed to be of shallow volcanic origin, masking completely the basement anomalies. In spite of this the depths to these shallow sources have been used when contouring as if they referred to basement. The inner half of Vøringplatået is similar in magnetic pattern to the shelf area inside. The magnetic basement reaches depths of about 6 km along the continental edge and seems to be at least 5 km deeep on the inner part of Vøringplatået.

The basement contours at Haltenbanken (64°40'N) represent a compromise. The large magnetic anomaly has a causative body at 5—8 km depth, while the small anomalies inside are caused by shallow bodies. These anomalies are evidently not due to the same magnetic marker. The shallow anomalies have been assumed to represent basement, and only depth determinations from the outer flank of the large anomaly have been considered when contouring. It is perhaps more likely to assume the shallow effects to be due to igneous dykes in the sediments. In this case the basement contours should be drawn 30 km closer to the coast in the actual area.

Discussion.

The fitting together of the Northern Continents in their predrift positions (e.g. Bullard et.al., 1965), does not allow for the existence of Vøringplatået which has, nevertheless, been considered a subsided part of the shelf by several authors (Demenitskaya and Dibner, 1966). As can be seen from Fig. 4 both the continental rise outside Møre (63°N) and at least the inner part of Vøringplatået should be considered of continental origin and allowed for when trying to fit the continents together. Concerning the central part of Vøringplatået, Johnson et. al. (1968) have given seismic evidence for a buried ridge probably related to volcanism. This interpretation is supported by the magnetic picture.

An earlier publication (Ivanov, 1967) indicating depths to magnetic basement exceeding 20 km deserves a closer examination. The depth estimates are based on the assumption that the magnetic bodies can be treated as lines of poles (Ivanov, 1967, p. 367). This is an unrealistic simplification leading to depths being far too great. Another factor of similar influence is the lack of knowledge about magnetic strike directions in the case of widely spaced profiles.

The seismic refraction profile of Ewing and Ewing (1959, Profile F-8), will be found in Fig. 4 at 65°15′N, 04°35′E. It is a one way shot with an apparent basement velocity of 4.1 km/sec. This low velocity may be due either to basement not having been reached or to downdip shooting. In both cases the depth tends to increase, thus giving a better agreement with the magnetic depth.

The publications of Kvale et. al. (1966) and Sellevoll et. al. (1967) show depths to acoustic basement (5.3 km/sec) which are in striking agreement with the depths to magnetic basement (Fig. 4). The only discrepancy is found at Haltenbanken (64°40′N, 8°50′E). The reason for this disagreement may be sought in the seismic depth determination (one way shot), in the magnetic determination, or in the fact that the two methods are not referring to the same physical parameters. Of these reasons the last is considered the most probable. It can be separated into two related possibilities:

1. The large magnetic anomaly at Haltenbanken may originate from far below the top of the basement.
2. The acoustic basement may be high velocity sediments, e.g. Devonian sandstones and conglomerates occurring in the costal areas inside

(Holtedahl, 1960a), the shallow magnetic effects inside the marginal channels being due to basic dykes in the sediments.

To be able to choose between these two alternatives additional work is required. The second alternative is, however, favoured due to the change in magnetic pattern at 64°20'N, 10°E.

Acknowledgements.

I thank Inge Aalstad, Director of Norges geologiske undersøkelse, Geofysisk avdeling for allowing me to publish the results of a large amount of work to which my contribution has been of minor importance.

The U.S. Naval Oceanographic Office is thanked for the permission to reproduce part of the «Total Magnetic Intensity Chart of the Norwegian Sea» and to publish interpretations made on that map and the accompanying microfilm records.

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NB! Magnetic isogam map under separate cover at the end of this yearbook.